DIGITAL EQUIPMENT CORPORATION

RESOURCE HANDBOOK $1.00

education

HUNTINGTON II Simulation Program—HARDY

computers are for kids — digital — EduSystems—expandable, economical

DIGITAL EQUIPMENT CORPORATION
EDUCATIONAL PUBLICATIONS

A partial list of the publications in the continuing series of curriculum material published by Digital for use with EduSystems and RSTS are listed below. Please inquire directly for prices on classroom quantities.

These publications may be ordered (cash enclosed) from:

Software Distribution Center
Digital Equipment Corporation
Maynard, Massachusetts 01754

Population: Self Teaching BASIC Workbook		$2.00
101 BASIC Computer Games		$5.00
Understanding Mathematics and Logic Using BASIC Computer Games		$1.50
BASIC Matrix Operations, Project Solo		$1.00
Computer Augmented Calculus Topics		$1.50
Problems for Computer Mathematics		$1.25
Advanced Problems for Computer Mathematics		$2.00
Tutorial Exercises for Chemistry	Student Workbook	$1.00
	Teacher's Resource	$2.75
BASIC Application Programs		
Mathematics I		$1.00
Mathematics II		1.00
Science		1.00
Business and Social Studies		1.00
Plotting		1.00
Chemistry		1.50
Huntington I Application Programs		
Mathematics		$2.00
Teacher Assistance		1.00
Huntington I Simulation Programs		
Biology		$1.00
Chemistry		2.00
Earth Science		1.00
Physics		2.00
Social Studies		1.00
Huntington II Simulation Modules		
Student Workbook		$.30 - .50
Teacher's Guide		.30 - .50
Resource Handbook		.50 - 1.00
Program Paper Tape		.50 - 1.00

RESOURCE MANUAL

HARDY

THE HARDY-WEINBERG PRINCIPLE

Developed by:

R. Cooperman, John Glenn High School
Huntington, New York
A. Frishman, State University of New York
Farmingdale, New York
K. Moy, State University of New York
Stony Brook, New York

Programmed by:

S. Hollander, State University of New York
Stony Brook, New York
C. Losik, State University of New York
Stony Brook, New York

Support material by:

R. Cooperman
K. Moy

Illustrations by:

K. Klassen, State University of New York
Stony Brook, New York

HUNTINGTON TWO COMPUTER PROJECT

Copyright © 1973, State University of New York

8 September 1973

The work of the Huntington Two Computer Project is partially supported by the National Science Foundation, Grant GW-5883.

PUBLISHED EXCLUSIVELY BY DIGITAL EQUIPMENT CORPORATION, 1973

HARDY

RESOURCE MANUAL

Table of Contents

I. The Hardy-Weinberg Principle 1

A. Introduction 1

B. Derivation of the Hardy-Weinberg Principle. . . 2

C. Applications of the Hardy-Weinberg Principle. . 6

D. Necessary Conditions for Genetic Equilibrium. . 6

II. Sample Runs 7

III. The *HARDY* Model 9

IV. Program Listing 10

V. Bibliography 13

HARDY

RESOURCE MANUAL

I. THE HARDY-WEINBERG PRINCIPLE

A. INTRODUCTION

The fact that a trait is dominant does not ensure that it will be prevalent in a population. *Polydactilism* in humans is the condition of being six-fingered. Strangely enough, this condition is dominant over the five-fingered condition. Yet about 97% of the population are five-fingered, leaving only 3% of the population with the dominant trait. Why, if polydactilism is dominant, aren't there more six-fingered individuals?

The answer to this seeming paradox can be found in a principle first formulated by an English mathematician, G. H. Hardy, and a German physician, W. Weinberg, in 1908. The Hardy-Weinberg Principle says that under certain constant conditions* the genotypic ratios for any single-gene characteristic remain the same from one generation to the next in a sexually reproducing population. In other words, under certain constant conditions, a genetic equilibrium is established for the population with regard to the trait in question.

The mathematical form of the Hardy-Weinberg Principle gives us a way of actually calculating these genotypic ratios. If we could look at the gene pool of a population with respect to the characteristic under study, we could observe the frequencies of the dominant and recessive alleles; i.e., the proportion of alleles for the trait that are dominant and the proportion that are recessive.

If we let P represent the frequency of the dominant allele and Q the frequency of the recessive allele, the Hardy-Weinberg Principle may be written:

$$P^2 + 2PQ + Q^2 = 1$$

At this point you may be wondering what this expression means and how it arises; how the Hardy-Weinberg Principle in this form can actually be used to calculate the genotypic ratios; or how the Principle explains the case of polydactilism, where a dominant characteristic is shown by only 3% of the population. In the following sections on the derivation of the Hardy-Weinberg Principle, you should be able to find answers to all these questions.

---

*See p.6 for necessary conditions.

B. DERIVATION OF THE HARDY-WEINBERG PRINCIPLE

Let us begin by looking at the gene pool of a population with regard to the dominant and recessive alleles for polydactilism. Suppose there are 1,000 people in our sample population and that 97% (.97) of this population display the five-fingered condition. This means that 970 people out of the 1,000 are homozygous recessive, while only 30 persons are either homozygous or heterozygous dominant. Before we can calculate the per cent of the next generation who will display the dominant or recessive trait, we must determine the make-up of the gene pool of the present generation. In other words, we must find the frequency of the dominant allele for polydactilism as well as the frequency for the recessive allele in the gene pool of the present population.*

P's and Q's

You'll recall that we let P represent the frequency of the dominant allele and Q the frequency of the recessive allele in the gene pool of our population. Assuming that there is no reason one allele should be inherited more easily than the other, how often each allele is inherited depends only on the frequency of the alleles in the gene pool. For this reason P and Q can also be thought of as the probability or chance of inheriting a dominant or recessive allele, respectively.

With P and Q so defined, we can refer to two simple laws of probability to help us determine actual values for P and Q. Once we have these values, we will be able to determine genotypic and phenotypic ratios for the next generation.

A Little Probability

There are many real-life situations or events where only two outcomes are possible. The tossing of a coin represents such an event: the outcome of a coin toss must be either heads or tails. If a coin is not weighted you know that on the average, over a large number of tosses, heads will show half the time. We can therefore say that the probability of getting heads is 1/2. We will use the following shorthand to represent this statement:

probability of heads = P(heads) = 1/2

Since we can also expect to get tails half the time,

probability of tails = P(tails) = 1/2

---

*This problem is actually solved in the *TEACHER MANUAL*.

Now suppose that we have a coin weighted to give heads more often than tails. We toss the coin a large number of times, recording the outcome of each toss, and find that 3 out of 4 times we get heads, while only 1 out of 4 times do we get tails. We can therefore say that the probability of getting heads is 3/4, while the probability of getting tails is 1/4:

$$P(\text{heads}) = 3/4$$

$$P(\text{tails}) = 1/4$$

Notice that for a fair coin:

$$P(\text{heads}) + P(\text{tails}) = 1/2 + 1/2 = 1$$

and for the weighted coin:

$$P(\text{heads}) + P(\text{tails}) = 3/4 + 1/4 = 1$$

The significance of the probabilities of the individual outcomes adding up to 1 is that only two outcomes (getting heads or getting tails) are possible in each case, and that each time the coin is tossed, one or the other outcome must occur.* We can generalize our experience with coin-tossing to obtain our first law of probability:

LAW #1: THE SUM OF THE PROBABILITIES OF ALL THE POSSIBLE OUTCOMES FOR A GIVEN EVENT MUST EQUAL 1.

With this knowledge we can work backwards to obtain the probability of a specific outcome when we know the probabilities of all other outcomes.

A Little More

Our second law of probability deals with what are known as independent events. Independent events are events which, generally speaking, have no effect on each other. More precisely, the occurrence or nonoccurrence of one event does not change the probability of the other event occurring, if the two events are independent. Successive tosses of a coin constitute such independent events: obtaining heads or tails on one toss in no way affects the probability of getting heads or tails on the next toss. It turns out that for any two independent events the following is true:

---

*We're assuming that the coin can't land on its edge -- and stay there.

LAW #2: *THE PROBABILITY THAT BOTH EVENTS OCCUR IS EQUAL TO THE PROBABILITY OF ONE EVENT TIMES THE PROBABILITY OF THE OTHER EVENT.*[*]

We can use our second law to find the answer to such problems as calculating the probability of obtaining first heads, then tails, on two successive tosses of a coin. Since P(heads) = 1/2 and P(tails) = 1/2 for a fair coin, and successive tosses of a coin constitute independent events,

$$\begin{aligned} P(\text{obtaining heads, then tails}) &= P(\text{heads}) \times P(\text{tails}) \\ &= 1/2 \times 1/2 \\ &= 1/4 \end{aligned}$$

Probability and the Hardy-Weinberg Principle

Now we will apply the probability we have learned to the case of gene inheritance to obtain the Hardy-Weinberg Principle. Recall that we said P and Q represent the *probabilities* of inheriting a dominant or recessive allele respectively, as well as the *frequencies* of the dominant and recessive alleles within the gene pool of a population. Assuming there are only two alleles for a specific trait (and, therefore, only two possibilities for inheritance), we have by LAW #1 that the probability of inheriting the dominant allele plus the probability of inheriting the recessive allele equals 1; i.e.,

$$\boxed{P + Q = 1}$$

according to our notation. Our second law of probability told us something very useful about independent events: for two independent events, the probability that both events occur is obtained by multiplying the probability of one event by the probability of the other. The key point to remember is that the inheritance of one allele is independent of the inheriting of the other. By LAW #2 then, the probability of inheriting any combination is equal to the probability of inheriting one allele times the probability of inheriting the other:

$$P(\text{inheriting any two alleles}) = P(\text{inheriting one allele}) \times P(\text{inheriting other allele})$$

---

[*] Our second law can be generalized to apply to cases with any number of independent events n: *FOR N INDEPENDENT EVENTS, THE PROBABILITY THAT ALL N EVENTS OCCUR EQUALS THE PRODUCT OF THE PROBABILITIES OF THE N INDIVIDUAL EVENTS.*

Now we can determine the probability of being homozygous dominant (H-D), heterozygous dominant (h-D), or homozygous recessive (H-R), with respect to a characteristic for which we know P and Q within the population:

$$\begin{aligned} P(\text{being H-D}) &= P(\text{inheriting dominant allele}) \times \\ & P(\text{inheriting dominant allele}) = P \times P = \boxed{P^2} \end{aligned}$$

$$\begin{aligned} P(\text{being h-D}) &= P(\text{inheriting dominant allele}) \times \\ & P(\text{inheriting recessive allele}) \\ &+ P(\text{inheriting recessive allele}) \times \\ & P(\text{inheriting dominant allele}) \\ &= (P \times Q) + (Q \times P) = PQ + QP = \boxed{2PQ} \end{aligned}$$

$$\begin{aligned} P(\text{being H-R}) &= P(\text{inheriting recessive allele}) \times \\ & P(\text{inheriting recessive allele}) = Q \times Q = \boxed{Q^2} \end{aligned}$$

Notice that the probability of being heterozygous dominant is 2 PQ. This is understandable because an individual can be h-D in two ways: either by inheriting the dominant allele from the mother and the recessive allele from the father or vice versa.

What do the probabilities P^2, 2PQ and Q^2 represent in terms of the frequencies of different genotypes in the population? Well, if you again recall that the probabilities P^2, 2PQ and Q^2 can be thought of as proportions, the answer is obvious: P^2 is the proportion of the population that is H-D; 2PQ the proportion that is h-D, and Q^2 the proportion that is H-R.

Because any individual within the population must be either H-D, h-D, or H-R with regard to the characteristic in question, the proportions P^2, 2PQ and Q^2 include the total population. By LAW #1, then, the sum total of these proportions is equal to 1 (100% of the population):

$$\boxed{P^2 + 2PQ + Q^2 = 1}$$

This is the Hardy-Weinberg Principle.

C. APPLICATIONS OF THE HARDY-WEINBERG PRINCIPLE

The Hardy-Weinberg Principle gives us a way of determining the genotypic and phenotypic ratios for a population with regard to a specific trait once we know P and Q, the frequencies of the dominant and recessive alleles within the gene pool of the population. Conversely, if we know the genotypic ratios (all we need, actually, is the proportion of the population that is recessive: Q^2), we can determine the allele frequencies P and Q.

It is easy to see from the Hardy-Weinberg Principle that if P and Q remain the same from one generation to the next, so will the genotypic ratios. For this reason the fact that a trait is dominant does not imply that it will be increasingly prevalent in a population as evidenced by the case of polydactilism. The genotypic ratios will change only if something upsets the genetic equilibrium.

D. NECESSARY CONDITIONS FOR GENETIC EQUILIBRIUM

The following conditions must be met in order for P and Q to remain the same and for a genetic equilibrium to exist:

1) The population must be large enough so that chance alone cannot significantly affect gene frequencies.

2) The amount of immigration or emigration is negligible.

3) There is essentially no mutation or there is mutational equilibrium.

4) Individuals of each genotype have equal chances of surviving and leaving offspring.

5) Mating is entirely random. (There is no selection for a particular trait.)

II. SAMPLE RUNS

The following runs illustrate the solution of the three problems presented in the *STUDENT* and *TEACHER MANUALS*.

PROBLEM 1: Assume that the gene for white wool in sheep is dominant over the gene for black wool. If 250 out of 1000 sheep observed in a large population have black wool, what per cent are homozygous white and what per cent are heterozygous white?

```
DO YOU WISH TO COMPILE YOUR OWN INFORMATION ON A SPECIFIC
TRAIT (1=YES, 0=NO) ?1

NUMBER OF ORGANISMS EXAMINED ?1000
NUMBER OF ORGANISMS SHOWING RECESSIVE TRAIT ?250

WHAT PROPORTION OF THOSE EXAMINED SHOWED THE RECESSIVE TRAIT
THIS IS Q*Q ?.25


Q = 0.5

GENOTYPE                          PROPORTION     NUMBER
--------                          ----------     ------
HOMOZYGOUS DOMINANT                0.25           250
HETEROZYGOUS DOMINANT              0.5            500
HOMOZYGOUS RECESSIVE               0.25           250
```

PROBLEM 2: If we know that 128 out of 200 people surveyed for being tasters or nontasters of PTC show the dominant characteristic, what per cent of the general population (approximately 1000 people) are heterozygous?

```
NUMBER OF ORGANISMS EXAMINED ?200
NUMBER OF ORGANISMS SHOWING RECESSIVE TRAIT ?72

WHAT PROPORTION OF THOSE EXAMINED SHOWED THE RECESSIVE TRAIT
THIS IS Q*Q ?.36


Q = 0.6

GENOTYPE                          PROPORTION     NUMBER
--------                          ----------     ------
HOMOZYGOUS DOMINANT                0.16            32
HETEROZYGOUS DOMINANT              0.48            96
HOMOZYGOUS RECESSIVE               0.36            72
```

PROBLEM 3: **Polydactilism in humans is the condition of being six-fingered. Although this condition is dominant over the five-fingered condition, 97% of the general population are five-fingered. What per cent of the population are homozygous dominant and what per cent are heterozygous?**

```
NUMBER OF ORGANISMS EXAMINED ?100
NUMBER OF ORGANISMS SHOWING RECESSIVE TRAIT ?97

WHAT PROPORTION OF THOSE EXAMINED SHOWED THE RECESSIVE TRAIT
THIS IS Q*Q ? .97


Q = 0.984886

GENOTYPE
---------                               PROPORTION      NUMBER
                                        ----------      ------
HOMOZYGOUS DOMINANT                      0                  0
HETEROZYGOUS DOMINANT                    0.03               3
HOMOZYGOUS RECESSIVE                     0.97              97
```

III. THE *HARDY* MODEL

ASSUMPTIONS

The Hardy-Weinberg Principle and consequently the *HARDY* program operate under certain assumptions as listed in Part I, Section D, of this Manual. (Please see page 6.)

LIST OF VARIABLES

P	Frequency of Dominant Allele (or probability of inheriting dominant allele)
Q	Frequency of Recessive Allele (or probability of inheriting recessive allele)
T	Designation for Dominant Allele
T1	Designation for Recessive Allele
S1	Sample Size
R1	Number Recessive

EQUATIONS

(Please see Part I of this Manual for explanation and more detailed development.)

i) $P + Q = 1$

ii) $P^2 + 2PQ + Q^2 = 1$

IV. PROGRAM LISTING

```
100 REM HARDY -- PROGRAM ON THE HARDY-WEINBERG GENETICS PRINCIPLE
110 REM COPYRIGHT 1973 - STATE UNIVERSITY OF NEW YORK
120 REM P=FREQUENCY OF T ALLELE (DOMINANT),
130 REM Q=FREQUENCY OF T1 ALLELE (RECESSIVE)
140 REM S1=SAMPLE SIZE, R1=NUMBER RECESSIVE
150 REM DEVELOPED BY K. MOY, R. COOPERMAN, AND A. FRISHMAN
160 REM PROGRAMMED BY C. LOSIK, JANUARY 1972
170 REM LATEST REVISION: 11-28-73
180 REM LET Q=RND(1)
190 RANDOMIZE
200 PRINT "POPULATION GENETICS STUDY - THE HARDY-WEINBERG PRINCIPLE"
205 LETN=6
210 PRINT
220 PRINT "HAVE YOU TRIED THIS PROGRAM BEFORE (1=YES, 0=NO)";
230 INPUT B
240 IF B=1 THEN 390
250 IF B<>0 THEN 210
260 PRINT
270 PRINT"     THE HARDY-WEINBERG PRINCIPLE PROVIDES A SIMPLE WAY"
280 PRINT"TO CALCULATE THE PROPORTION OF ORGANISMS IN A POPULATION"
290 PRINT"THAT ARE HOMOZYGOUS DOMINANT, HETEROZYGOUS DOMINANT, OR"
300 PRINT"HOMOZYGOUS RECESSIVE WITH REGARD TO A SPECIFIC TRAIT.  ALL"
310 PRINT"WE NEED TO DETERMINE THESE PROPORTIONS ARE THE PROPORTION OF"
320 PRINT"ALLELES IN THE GENE POOL WHICH ARE DOMINANT FOR THIS TRAIT"
330 PRINT"(P) AND THE PROPORTION WHICH ARE RECESSIVE (Q)."
340 PRINT
350 PRINT"WE WILL GIVE YOU A POPULATION OF RATS TO WORK WITH.  SOME"
360 PRINT"HAVE SHORT HAIR, SOME HAVE LONG HAIR.  SHORT HAIR IS"
370 PRINT"DOMINANT, LONG HAIR RECESSIVE.  THERE ARE 1000 SPECIMENS."
380 GO TO 510
390 PRINT"DO YOU WISH TO COMPILE YOUR OWN INFORMATION ON A SPECIFIC"
400 PRINT"TRAIT (1=YES, 0=NO)";
410 INPUT C
420 IF C=1 THEN 740
430 IF C<>0 THEN 390
440 PRINT "DO YOU WANT: 1=THE ORIGINAL RAT POPULATION, OR"
450 PRINT "2=A NEW RAT POPULATION.  WHICH";
460 INPUT N
470 IF N=1 THEN 510
480 IF N<>2 THEN 440
490 LET N=RND(1)
500 GO TO 520
510 LET N=.19
520 PRINT "HOW MANY RATS DO YOU WANT TO SAMPLE";
530 INPUT S1
540 IF S1<>INT(S1) THEN 520
550 IF ABS(S1-501)>500 THEN 520
560 PRINT
570 IF S1>25 THEN 600
580 PRINT "RAT  PHENOTYPE"
590 PRINT "---  ---------"
```

```
600 LET R1=0
610 FOR I=1 TO S1
620 LET Q=RND(I)
630 IF Q<N THEN 670
640 IF S1>25 THEN 700
650 PRINT I;"  SHORT HAIR"
660 GO TO 700
670 LET R1=R1+1
680 IF S1>25 THEN 700
690 PRINT I;"  LONG HAIR"
700 NEXT I
710 PRINT "TOTAL NUMBER RECESSIVE =";R1
720 PRINT "TOTAL NUMBER DOMINANT =";S1-R1
730 GO TO 840
740 PRINT
750 PRINT "NUMBER OF ORGANISMS EXAMINED";
760 INPUT S1
770 IF S1<1 THEN 750
780 IF S1<>INT(S1) THEN 750
790 PRINT "NUMBER OF ORGANISMS SHOWING RECESSIVE TRAIT";
800 INPUT R1
810 IF R1<>INT(R1) THEN 790
820 IF R1<1 THEN 790
830 IF R1>S1 THEN 750
840 PRINT
850 PRINT"WHAT PROPORTION OF THOSE EXAMINED SHOWED THE RECESSIVE TRAIT"
852 PRINT"THIS IS Q*Q";
880 INPUT N
890 IF ABS(N-.5)<=.5 THEN900
891 PRINT"PLEASE INPUT THE PROPOPORTION IN THE FORM OF A"
892 PRINT"DECIMAL NUMBER BETWEEN 0.00 AND 1.00"
894 GOTO850
900 IF ABS(N-R1/S1)<.01 THEN 930
910 PRINT "PLEASE CHECK YOUR CALCULATIONS."
920 GO TO 850
930 LET Q=SQR(R1/S1)
940 LET P=1-Q
950 PRINT
960 PRINT
970 IF B=1 THEN 1270
```

```
971 PRINT
975 PRINT"------------------------------------------------------------"
976 PRINT
980 PRINT "TO DETERMINE THE VALUE OF P AND Q AND THE GENOTYPIC"
990 PRINT  "RATIOS, RECALL THAT:"
1000 PRINT
1010 PRINT "1.  P + Q = 1 SINCE THE PROPORTION OF ALLELES IN THE GENE"
1020 PRINT "    POOL WHICH ARE DOMINANT FOR A TRAIT PLUS THE"
1030 PRINT "    PROPORTION WHICH ARE RECESSIVE REPRESENT ALL ALLELES"
1040 PRINT "    IN THE GENE POOL,"
1050 PRINT
1060 PRINT "2.  P*P REPRESENTS THE PROPORTION OF THE POPULATION THAT"
1070 PRINT "    ARE HOMOZYGOUS DOMINANT,"
1080 PRINT
1090 PRINT "3.  2*P*Q REPRESENTS THE PROPORTION THAT ARE HETEROZYGOUS"
1100 PRINT "    DOMINANT,"
1110 PRINT
1120 PRINT "4.  Q*Q REPRESENTS THE PROPORTION OF THE POPULATION THAT"
1130 PRINT "    SHOW THE RECESSIVE TRAIT, I.E. THAT ARE HOMOZYGOUS"
1140 PRINT "    RECESSIVE,"
1180 PRINT
1190 PRINT "5.  P*P + 2*P*Q + Q*Q = 1 SINCE THE PROPORTION OF THE"
1200 PRINT "    POPULATION THAT ARE HOMOZYGOUS DOMINANT, PLUS THE"
1210 PRINT "    PROPORTION THAT ARE HETEROZYGOUS, PLUS THE"
1220 PRINT "    PROPORTION THAT ARE HOMOZYGOUS RECESSIVE REPRESENT"
1230 PRINT "    THE TOTAL POPULATION."
1240 PRINT
1241 PRINT"------------------------------------------------------------"
1250 PRINT
1260 PRINT "IN THE ABOVE EXAMPLE, ";
1270 PRINT "Q =";Q
1280 PRINT
1290 PRINT "GENOTYPE"," ","PROPORTION","NUMBER"
1300 PRINT "--------"," ","-----------","------"
1310 PRINT "HOMOZYGOUS DOMINANT",INT(100*P*P+.5)/100,
1313 LETZ9=INT(P*P*S1+.5)
1314 GOSUB 1400
1320 PRINT "HETEROZYGOUS DOMINANT",INT(200*P*Q+.5)/100,
1323 LETZ9=INT(2*P*Q*S1+.5)
1324 GOSUB 1400
1330 PRINT "HOMOZYGOUS RECESSIVE",INT(100*Q*Q+.5)/100,
1333 LETZ9=INT(Q*Q*S1+.5)
1334 GOSUB 1400
1340 PRINT
1350 PRINT
1360 PRINT "DO YOU WISH TO REPEAT THIS PROGRAM (1=YES, 0=NO)";
1370 INPUT B
1380 IF B=1 THEN 390
1390 IF B<>0 THEN 1360
1399 STOP
1400 IFZ9=0 THEN 1415
1405 PRINTTAB(44-INT(LOG(Z9+.005)/LOG(10)));Z9
1410 RETURN
1415 PRINTTAB(44);0
1420 RETURN
2000 END
```

V. BIBLIOGRAPHY

HIGH SCHOOL TEXTS

BIOLOGICAL SCIENCE: MOLECULES TO MAN
BSCS (Blue) 3rd Edition
Houghton Mifflin Company, Boston (1973) p.359 and p.622

BIOLOGICAL SCIENCE: AN INQUIRY INTO LIFE
BSCS (Yellow) 3rd Edition
Harcourt, Brace, Jovanovich, Inc., New York (1973) p.762

BIOLOGY: AN INQUIRY INTO THE NATURE OF LIFE
Stanley L. Weinberg
Allyn and Bacon, Inc., Boston (1971) pp.462-63

COLLEGE TEXTS

BIOLOGICAL SCIENCE
William T. Keeton
W. W. Norton and Company, New York (1967) pp.655-57

GENETICS
Robert C. King
Oxford University Press, New York (1962) Ch. 17

GENETICS
Monroe W. Stickberger
Macmillan Company, New York (1968) Part VI

THE SCIENCE OF BIOLOGY
Paul B. Weisz
McGraw-Hill Book Company, New York (1967) Ch. 31

ADVANCED COLLEGE TEXT

MATHEMATICAL IDEAS IN BIOLOGY
J. Maynard
Cambridge University Press, Cambridge (1968) Ch. 5

PERIODICALS

"Genetic Drift in an Italian Population"
Luigi Luca Cavalli-Sforza
SCIENTIFIC AMERICAN, August 1969, p.30

"Population Genetics and Human Origins"
Robert E. Eckhardt
SCIENTIFIC AMERICAN,January 1972, p.94

"Genetic Load"
Christopher Wills
SCIENTIFIC AMERICAN, March 1970